Mitigating Abiotic Stress in Agriculture: Promising Technologies

ICAR–National Institute of Abiotic Stress Management

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Mitigating Abiotic Stress in Agriculture: Promising Technologies

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Preface

ICAR-National Institute of Abiotic Stress Management (NIASM) was established on February 21, 2009, and stands as a significant national institute under the agegis of Indian Council of Agricultural Research. Serving as a unique hub for fundamental and strategic research, NIASM focuses on evaluating mechanisms and crafting robust tools and technologies to address abiotic stresses within agricultural systems. The institute's research initiatives are designed to foster multidisciplinary teams of scientists leveraging cutting-edge technologies to minimize the adverse impacts of abiotic stresses in agriculture. Equipped with state-of-the-art facilities, including laboratories, high-tech greenhouses, plant phenomics facilities, experimental research farms, and units for animals and fisheries research, NIASM has dedicated its initial efforts to developing these resources. Some emerging technologies exhibit the potential to substantially enhance farmers' income by effectively managing abiotic stresses.

ICAR-NIASM, Baramati, in its 16 years after inception has few of the impactful initiatives and remarkable milestones to its credit. The institute has successfully developed technologies addressing diverse challenges, such as transforming degraded land into productive fruit orchards, pollination and shade management techniques for dragon fruit, introducing water-saving methods for fruits and vegetable crops, utilizing bio-regulators to enhance vegetable yields, optimizing trash, tillage, and nutrient management in sugarcane, establishing climate-resilient integrated farming systems (IFS), creating mixed-nutrition silage from sugarcane, developing nano-products to alleviate multiple stresses in fisheries; wastewater management for floriculture;. climate resilient chara bank for round-the-year fodder availability for livestock in drought-prone regions; strategic pruning for enhancing productivity of dragon fruit in multi-stressed regions; wider pit and trench planting techniques: enhancing fruit production and quality on shallow rocky barren lands;enhancing quinoa yield and sustainability in shallow basaltic semi-arid regions; and trenching and transforming filled-in soil technology for dragon fruit. These technologies are anticipated to help farmers resolve the grappling issues with abiotic stressors.

After 16 years of unwavering commitment, ICAR-NIASM, Baramati, takes pride in showcasing the scientific accomplishments achieved by its multidisciplinary research teams. This technology bulletin serves as a snapshot of the institute's most significant achievements. It is anticipated that the information provided herein will prove invaluable for farmers, contributing to the improvement of the agricultural, horticultural, animal, and fisheries sectors in the semi-arid region.

Director

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Introduction

Abiotic stresses exert a pivotal influence on the productivity, sustainability, and resilience of Indian agriculture, with diverse agro-climatic zones making the country susceptible to a range of challenges. From droughts and erratic rainfall to extreme temperatures and soil-related issues, these stresses significantly impact crop yields, threatening food security. Climate change-induced stresses can result in a drastic reduction of up to 70% crop yield, while edaphic stresses like nutrient deficiencies and salinity further compound challenges in crop production. Livestock and aquatic ecosystems also face health and productivity risks due to abiotic stresses.

Addressing these multifaceted challenges requires a holistic and interdisciplinary approach, integrating ecological, agricultural, and socio-economic dimensions. Maharashtra, as the third-largest state in India, boasts significant agricultural achievements, yet it grapples with the adverse effects of global climate change. Rising temperatures, erratic precipitation, and soil salinization jeopardize agriculture production and stability.

Recognizing the urgency, the ICAR-National Institute of Abiotic Stress Management (NIASM), established in 2009, has been at the forefront of developing efficient technologies to manage abiotic stresses. Focused on atmosphere, water, and soil-related stresses, NIASM plays a crucial role in mitigating losses in crop, animal, and fisheries sectors. With the escalating challenges posed by climate change, the institute's primary goal is to evolve adaptive and mitigation strategies through cutting-edge scientific research.

Over the past 16 years, NIASM has assessed vulnerabilities in various agricultural sectors and pioneered innovative abiotic stress management technologies. As climate-induced stresses continue to amplify, there is an imperative need to upscale these technologies to the fields of Maharashtra, empowering farmers to combat abiotic stresses effectively. In light of this, the ICAR-NIASM's abiotic stress management technologies are compiled to facilitate widespread dissemination to farmers. The anticipation is that KVKs and the state agriculture department will play a pivotal role in disseminating these technologies through on-farm testing and frontline demonstrations in adopted villages.

Technology Number: 01

Transforming barren rocky basaltic terrain into cultivation for arable and horticultural crops

DD Nangare, P Suresh Kumar, Yogeshwar Singh, GC Wakchaure, SK Bal, PS Minhas, V Rajgopal, SV Ghadge and Pravin Taware

School of Drought Stress Management

Recommendation Domain: Barren rocky basaltic terrain with shallow murrum soil in the Deccan region of India.

Existing Practice: The area under rocky, barren land is not cultivated due to the absence of productive soil, limited water, and undulating topography mainly covered with grass. It is unsuitable for cultivating any crops, including horticulture crops, due to shallow soil and hardpan.

Improved Technology: The ICAR-NIASM has developed viable technology for transforming uncultivable rocky basaltic terrain into productive land within short period of three years. The steps involved in bringing the shallow basaltic rocky land to productive land are:

For Field Crops:

- The sloppy land is subdivided into terraces and subplots based on the topography across the slopes. The top 0.1-0.3 m murrum soil is scrapped and heaped at places using a bulldozer.
- Ripping and chaining are done by heavy machinery to break the weathered and non-weathered rock/murrum fragments down to the 0.9 m depth through its tynes.
- The exposed hard rocky portions left in patches after chaining and ripping by the heavy dozers are further shattered by controlled blastings. Series of holes of approximately 50 mm diameter are drilled using semi-automated tractor-operated Post-hole digger at spacing of 0.5-1 m and 0.6-0.9 m depth depending upon the hardness of the rock, followed by controlled blasting, which creates micro-cracks across the blasted terrain.
- Distillery spent wash from sugarcane industries is then applied on the fractured hard rocky portion to augment the process of soil development by chemical disintegration.
- The rocky basaltic/ zeolitic boulders/stones get softened by spent wash treatment and, being vulnerable to disintegration, are further broken down into smaller pieces of gravel by single/double passes of tractor ploughing.
- Land levelling of field plots are done to optimize water use, improve crop establishment, and reduce the irrigation time, thus reducing the efforts required to grow the crop.
- Since native murrum soil plots have low fertility status (C ~ 0-0.04% and available N and P ~14 and 1.4 kg/ha, respectively), these are enriched with organic carbon by sowing green manuring crops along with the application of Spent Mushroom Substrate (SMS).
- As black soil benefits crop growth, filling top strata with black soil to a depth of 2ft is recommended by transporting black soil from outside.


Step 1: Ripping/chaining of rocky surface


Step 2: Blasting


Step 3: Removal and collection of the heavy boulder for road filling


Step 4: Application of Spent wash to field


Step 5: Application of spent mushroom substrate


Step 6: Levelling of field plots


Step 7: Sowing of Dhaincha crop

Initial Condition of land


Condition of land after four years


Ripping and chaining with heavy machineries


Making pits with Pokhlain/JCB


Making pits with post hole digger


Preparing for microblast


Depth of auger pit after blasting


Depth of normal pit after balsting


Filling of pits with different soil mixtures


Performance of Pomegranate orchard



Nagpur mandarin established on raised beds

Innovative planting methods for establishment of orchards in shallow basaltic terrain

For Fruit crops:

- Sub-surface water harvesting (SSWH) with larger pits/trenches and micro-blasting in pits is beneficial in establishing Sapota, Guava and Pomegranate as the underlying murrum/rock often hinders the growth of deep-rooted plants in shallow basaltic terrain.
- The main root in the tap root system of fruit crops tends to penetrate vertically in deeper layers. Therefore, to increase the accessible water storage capacity from these shallow basaltic soils and for better root proliferation, it is advised to take up larger pits or trenches. About 1.0 m3 of murrum below the 1 m depth of the planting pit is shattered and fragmented by controlled micro-blasting and filled with the native murrum-black soil mixture(1:1 ratio).
- Raised bed planting/mounding with stone pitching or plastic mulching is another way to enlarge the rooting volume on shallow soils. This is done by scraping the surface soil or ripping followed by scraping where topsoil volume is minimal to create a raised bed.
- Typically, raised beds of about 0.5 m in height are recommended for planting fruit trees. However, under arid, basaltic conditions, the broad raised beds of 1.5 m width with a minimum height of 0.8-1.0 m are better to provide sufficient loose and friable soil for root growth in Nagpur mandarin and acid lime.

Performance: The performance of field crops and fruit crops is very good, and they are performing better after using the above-listed methods to establish orchards in shallow basaltic soil in rocky basaltic terrain. For developing 1 ha of rocky basaltic terrain into productive land, the cost will vary from Rs 55,000-70,000 depending upon the nature of the slope and the extent of rock hardiness. Farmers can generate an income of Rs 60,000 from the second year onwards, which would gradually increase with time due to increased yield from increasing soil content.

Impacts and Upscaling: The above-listed technologies have been demonstrated at the ICAR-NIASM experimental farm, providing valuable insights for transforming barren land into cultivable fields and orchards in shallow murrum soil. Farmers from nearby institutes have already adopted techniques of spent wash application and importing black soil to fill field plots on degraded rocky shallow basaltic land to expand the area under crop cultivation. Recently established ICAR institutes, like ICAR-NIBSM, Ranchi, and ICAR-DOFR, Pune, after seeking technical guidance from ICAR-NIASM, have utilized these insights to develop their farms under similar conditions. There is potential to use this technology to bring the similarly degraded lands of the Deccan region (about 26.5 million hectares) under cultivation with supportive government policies. This would help improve the socio-economic status of farmers by providing a means for income generation through the cultivation of horticulture crops using improved planting techniques in shallow basaltic soil, which was not possible earlier.

Technology Number: 02

Supplementary manual pollination: A potential technology to enhance the productivity of Dragon fruit

Boraiah KM, Basavaraj PS, Harisha CB, Vijaysinha D Kakade

School of Drought Stress Management

Recommendation domain: This technology is recommended to dragon fruit farmers, specifically those growing white-fleshed varieties that suffer from smaller and irregular fruit sizes. The technology will also be helpful to all dragon fruit growers, irrespective of the variety, as post-rainy supplementary pollination to prevent yield losses occurring due to rain-induced pollen washout.

Existing practices: Manual pollination, which is labour-intensive and time-consuming, is not widely adopted in dragon fruit cultivation. Some farmers, however, engage in this practice using traditional methods, collecting pollen in containers and manually pollinating with a camel brush.

Improved technology: A simple and easy manual method of self and cross-pollination that utilizes no kit was developed to resolve the rain-induced yield losses and production of abundant smaller fruits.

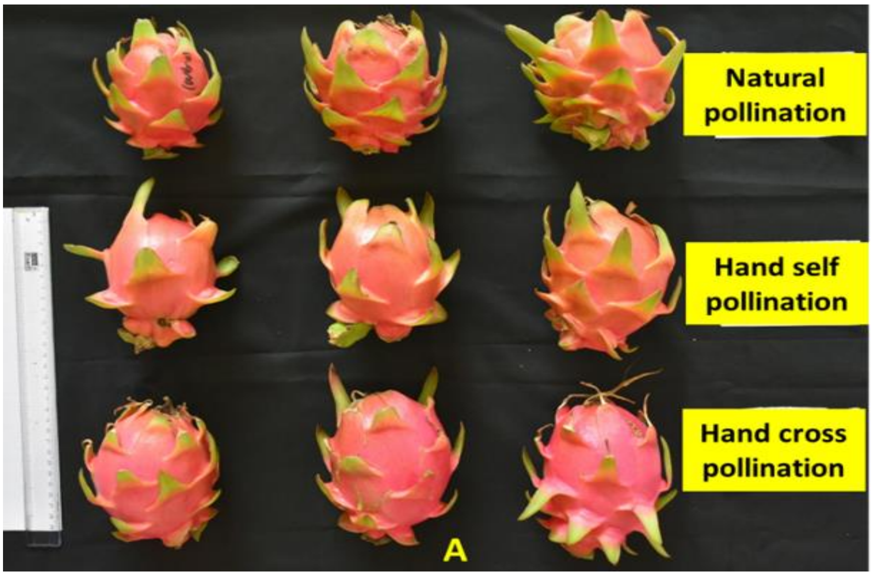
A. Self-pollination: Pollinating the flower's stigma using pollens from the same /different flower from the same plant or other plants of the same variety. It can be done with or without emasculation, as described below.

a) *With emasculation:* After confirmation of anther dehiscence in the evening (around 4.00 PM onwards) on the day of anthesis, emasculate the flower and pollinate using the pollens from removed floral part (dusting the pollens of the same flower to the stigma). Pollens of one flower can be used to pollinate 8-10 flowers.

b) *Without emasculation:* Hand self-pollination can be done on the next day of anthesis in the early morning hours without emasculation just by gently rubbing the stigma on the anthers of the same flower or another detached flower.

B. Cross-pollination: Pollinating the stigma (female) of the flowers using pollens (male) from the flowers of another variety. For instance, pollinating white type flower's stigma with pollens from red one. Emasculate the female flowers before anthesis or well in advance, even forenoon/afternoon on the day of anthesis and pollinate emasculated flowers using fresh (collected after dehiscence) or stored viable pollens of different varieties. However, emasculation and pollination can be done simultaneously. However, identifying the best pollen source/male parent is crucial.

Performance: Supplementary self and cross-pollination increase fruit size up to 40% and 100%, respectively, over natural pollination (245 g), besides enhancing the quality by production of 60-70% higher grade (350-450 g) with bright-coloured fruits.



Size of dragon fruit through supplementary manual pollination

Impacts and Upscaling: This technology was demonstrated to more than 100 farmers through on-farm and hands-on training. This technology can be spread widely through KVKs and state agricultural departments.

Technology Number: 03

Sunburn management in Dragon fruit through artificial shading

Vijaysinha D Kakade, Amol Patil, SB Chavan, Vanita S Salunkhe, BM Kalalbandi, KM Boraiah, AS Morade, DD Nangare

School of Edaphic Stress Management

Recommendation Domain: Dragon fruit cultivation predominates in semi-arid and hot-humid regions of Maharashtra, Gujarat, Karnataka, Tamil Nadu, Andhra Pradesh, Telangana, and West Bengal. These regions often experience summer temperatures that surpass 35°C, posing challenges for farmers due to sunburn issues. This technology is applicable in these regions to prevent sunburn injury caused by high-temperature stress.

Existing Practice: Numerous dragon fruit farmers are grappling with the challenge of sunburn due to CAM nature of the plant. Unlike other plants, dragon fruit do not have evaporative cooling due to closed stomata during the daytime, which leads to severe yellowing of cladode and stem rot. This stress depletes chlorophyll, increases disease vulnerability, hampers vegetative and reproductive growth, and compromises fruit yield and quality. Some farmers leave their plants untreated, while others resort to reducing irrigation. Very few farmers employ green shade nets (50%) and some spray kaolin (5 to 10%) to manage sunburn. Kaolin offers protection against sunburn by reflecting sunlight but does not modify the microclimate required for plant growth like shade net.

Improved Technology: Sunburn management technique through artificial shading is developed at ICAR-NIASM, Baramati, between 2022 and 2023. Based on effectiveness, we recommend shade nets in the order of black > white > green, with each having 50% shade intensity. To adopt this technology, it is advised to install RCC poles or angles of height 8-10 m having a 'T' bar of 2 m at the top with 10 m intervals. During summer (April-May), shade nets with 2 m width should be positioned 0.75 m above the canopy. Shading can be removed with the onset of monsoon. The cost for erecting shade nets ranges between Rs 1.00 to 1.50 Lakhs per acre.

Performance: Shade nets proved effective in reducing light intensity and temperature by approximately 50% and 5-6°C, resulting in a significant decrease in sunburn (by >90%) and disease incidence (by 30-40%). It also led to an improvement in chlorophyll content, allowing plants to maintain photosynthesis during summer. Furthermore, shading advances flowering by at least 15 days, which is attributed to a modified microclimate under shade. Additionally, it contributed to an increase in fruitful cladodes and flower buds, fruit set and reduced flower bud drop compared to plants without shade. Using shade nets also improved fruit quality and yield (40-70%). Thus, for effective control of sunburn and improved yield of quality fruits, the recommended order of shade nets based on their effectiveness is black > white > green shade nets, all with a 50% shade intensity. The benefits include advanced flowering, reduced reliance on plant protection chemicals, enhanced moisture retention and fruit set with improved fruit quality, ultimately justifying the initial cost of implementing shade nets.

Sunburn management in dragon fruit through artificial shading

Impacts and Upscaling: This technology is being disseminated through TV talks, workshops, seminars, and social media programs. While some farmers have embraced green shade nets (50%), benefits can be maximized by incorporating black and white shade nets. Those farmers who have already adopted shade nets have experienced positive outcomes. Despite the high initial investment, positive impacts observed suggest a potential for broader adoption among farmers who can bear the cost. Hence, subsidies can be considered to alleviate the financial burden on farmers to facilitate the widespread adoption of this eco-friendly technology.

Technology Number: 04

Detection and integrated management of Stem Canker (*Neoscytalidium dimidiatum*) disease in Dragon fruit

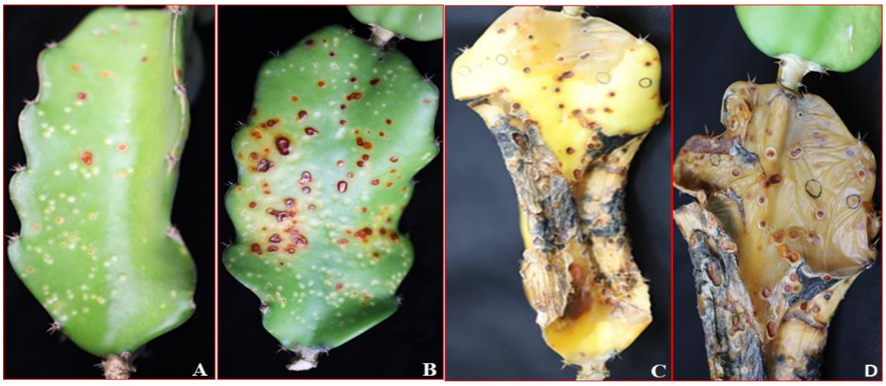
Vanita S Salunkhe, Vijaysinha D Kakade, SB Chavan

School of Edaphic Stress Management

Recommendation domain: Dragon fruit growing areas of Maharashtra, Karnataka, Kerala, Andhra Pradesh, West Bengal, and Gujarat.

Existing Situation: Dragon fruit (*Hylocereus spp*) is considered a 'super crop' due to its high nutritional value, ability to thrive under extreme climatic conditions, low maintenance costs and high net returns. However, its cultivation is facing considerable risk due to the emergence of diseases, and the risk is expected to increase further due to the impacts of climate change. Among the numerous diseases, stem canker stands out as a major menace, leading to a yield loss ranging from 30% to 80% in India's cultivation of dragon fruit. Stem canker not only endangers yield but also impacts fruit quality, emphasizing the crucial need for timely detection to manage this detrimental pathogen effectively.

Improved Technology: ICAR-NIASM conducted a detailed survey on dragon fruit orchards, identifying stem canker symptoms, starting with small chlorotic spots on infected cladodes. These spots evolved into raised lesions, turning necrotic with black pycnidia, leading to chlorosis and stem rot. The pathogen, *Neoscytalidium dimidiatum*, was isolated and identified through morphological and molecular techniques like DNA sequencing. Pathogenicity tests confirmed its role in stem canker. Disease transmission primarily occurs through contaminated cladodes. Effective management involves regular pruning in dormant periods, supplemented by Bordeaux mixture (1%) application and a scheduled fungicide spray combination.



Stages of symptom development in dragon fruit stem canker (A, B, C & D)

Performance: Timely identification of the causal agent empowers growers and plant pathologists to enact focused disease prevention and management measures, ensuring the sustainability and profitability of dragon fruit cultivation. Employing an integrated disease management approach can save 30-80% of yield loss in dragon fruit.

Impact and Upscaling: Early detection and efficient management can save up to 80% loss. The technology can be disseminated through Agro-advisories, KVKs and State Agriculture Department officials.

Technology Number: 05

Deficit irrigation strategies along with plastic mulch and bio-regulators to mitigate drought stress in horticulture crops

DD Nangare, P Suresh Kumar, Yogeshwar Singh, PS Minhas, Vijaysinha D Kakade, PS Khapate, SB Chavan, Pravin Taware

School of Drought Stress Management

Recommendation domain: Barren rocky basaltic terrain with shallow murrum soil in the Deccan region of India

Existing Practice: This rocky barren land, characterized by undulating topography and predominantly covered with grass, was previously uncultivated. The shallow soil and hardpan make it unsuitable for growing field crops, including horticulture crops. Traditionally, farmers have adopted the practice of planting trees in pits measuring 45×45×45 cm, filled with native soil (murrum) and Farm Yard Manure (FYM). Irrigation water can be applied manually or through a hose pipe.

Improved Technology: In the cultivation of Sapota, Guava, and Pomegranate, sub-surface water harvesting (SSWH) techniques were implemented using larger pits/trenches and micro-blasting due to the presence of underlying murrum/rock, which poses challenges for deep-rooted plants even in larger pits/trenches in shallow basaltic terrain. Recognizing the tap root system's vertical alignment tendency, efforts were made to enhance accessible water storage by adopting larger pits or trenches. To facilitate greater and deeper soil volumes for root growth, controlled micro-blasting shattered and fragmented approximately 1.0 m^3 of murrum beneath the 1 m depth of the planting pit. The resulting pits were filled with a mixture of native murrum and black soil in a 1:1 ratio.

Ripping and chaining

Making pits with Pokhlain/JCB

Making pits with post hole digger

Filling Pits with soil mixtures

Additionally, a drip irrigation system was designed and installed for all fruit crops. Deficit irrigation strategies, including Regulated Deficit Irrigation (RDI) and Partial root-zone drying (PRD), were employed for Pomegranate, Grape, and Tomato crops, accompanied by mulching and growth regulators to optimize water usage.

Grapes: To address challenges in establishing Grape orchards in shallow basaltic soils with low water retention and hard rocks, 0.75m wide and 0.60m deep trenches were created using a JCB/Pocklain machine. These trenches were filled with a 1:1 mixture of native murrum soil and black soil, along with 20 kg of farmyard manure (FYM) and 500 g of single super phosphate (SSP) fertilizer. This combination enhances root penetration and water conservation. The mixture of black soil and native murrum proved as a good mitigation option to tackle drought and edaphic stresses in Grape.

Performance: In tomato, the regulated deficit irrigation ($RDI_{0.8}$ i.e. 0.8×ETc) did not affect the marketable fruit yield (MFY) as compared with the full irrigation (FI; 78.0 Mg ha^{-1}). The water productivity of 19.2 kg m^{-3} was the maximum under $RDI_{0.8}$. The MFY was improved by 4% with deficit irrigation ($DI_{0.6}$) at vegetative stage while $DI_{0.6}$ at flowering stage showed little effect and a decline of 7% was monitored with $DI_{0.6}$ at fruiting stage. The $DI_{0.6}$ applied at either of two stages vegetative & flowering, flowering & fruiting and vegetative & fruiting resulted in 14-18% decline in yield.


In Papaya, the percent increase in yield and irrigation water use efficiency (IWUE) under partial root-zone drying with deficit irrigation is 8% and 8.5%, respectively for Papaya grown under shallow murrum soil. The yield and IWUE were found better under PRD irrigation and cultivated over native murrum soil as compared to mixed soil. Total phenolic content, total sugar, reducing sugar was observed higher under PRD compared to RDI treatment.


In Pomegranate, average increase in yield with PRD_{60} with mulch over the regulated deficit irrigation (RDI_{80}) was 7.6% with water saving of 25%. Under mulched condition, foliar spray of Salicylic acid (SA) helped in increasing yield of 3.7% in PRD60 over DI60. PRD-treated plants with a 60% irrigation level coupled with PGRs were found to have higher WUE (4.56-4.99 kg m^{-3}) than control irrigation to plants.

In water scarce area, pomegranate plants grown in shallow basaltic soils with 60% irrigation level coupled with SA (300 ppm) + NAA (45 ppm) can be recommended as it gave higher WUE 11.78% and 30.62% respectively, in DI and PRD. However, by adopting PRD strategy along with SA, WUE increased by 19.37% as compared to control.


In grape, (variety: Thompson seedless), the yield and irrigation water use efficiency (IWUE) under different irrigation treatments varies from 18 t ha^{-1} to 23 t ha^{-1} and 4.94 to 7.2 kg m^{-3}, respectively. The water saving of 29.2% was observed under applying deficit irrigation during shoot growth stages and berry growth stage of crop with yield reduction of 7.9% and increase of water productivity of 33% was found best. The IWUE was found more 6.2 kg m^{-3} in plant grown in mixed soil (native and black soil 50:50) followed by black (6.0 kg m^{-3}) and native soil 5.0 kg m^{-3}.


Recommendation: In tomato crops grown in shallow murrum soil under drip irrigation, the recommended deficit irrigation scheduled is 0.6 ET at vegetative stage followed by full irrigation at 1.0 ET at other growth stages for getting better yield and quality fruits. The average water saving will be 10% with average increase in yield of 5%. The tomato crop will tolerate interruptions of irrigation up to 15 days at growth stages and will help in minimizing yield losses by 3-7%. The papaya crops grown in shallow murrum soil will be irrigated with the partial root-zone drying strategy with 0.75 ET with an interval of 15 days to obtain maximum yield under limited water conditions. In pomegranate crop grown in shallow murrum soil, the partial root zone drying strategy with 0.6 ET with an interval of 15 days along with mulch and foliar application of salicylic acid should be followed to obtain maximum productivity under limited water conditions. Hence, the mixed soil i.e., 50:50 native murrum and black soil found suitable for planting of grape orchards to overcome the edaphic and drought stress and also improve water productivity of Grape. To achieve maximum water productivity under limited water condition in grapes, stress may be given during shoot growth stages (after April and October pruning) and berry growth development. The deficit irrigation strategies will help in minimizing the yield loss 5-8% and increase in water productivity 10-15 % under limited water conditions. Also, it will help in reducing the energy cost on drip irrigation by 10-12% for horticulture crops.

Impactss and Upscaling: Under water scarcity conditions, the regulated deficit irrigation in tomatoes and partial root-zone drying irrigation strategy with drip irrigation in tomatoes, papaya, pomegranate and grape will help the farmers to improve their cultivation practices, improved water productivity and quality of the horticulture produce along with reducing energy cost, for crops grown in shallow basaltic terrain under semi-arid region. This technology is demonstrated in our experimental orchards. This technique was applied by nearby farmers those are having this type of land. During the visit, mostly all the visitors including farmers, students, and scientific colleagues appreciated the technology used for this land and region.

Technology Number: 06

Bio-regulators for proving resilience to agriculture under water stress conditions

GC Wakchaure

School of Drought Stress Management

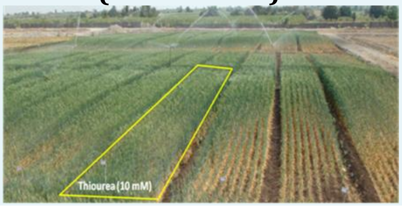
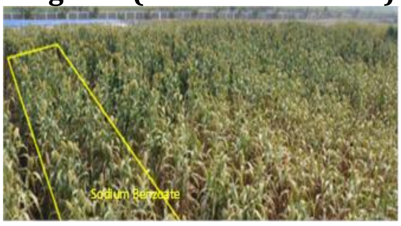
Recommendation Domain: Drought or water deficit stress-prone regions of India (Gujarat, Western Uttar Pradesh, North-West Madhya Pradesh, Western Rajasthan, Andhra Pradesh, Maharashtra, Odisha, Jammu and Kashmir, Central-East Tamil Nadu)

Existing Practice: Among abiotic stresses, water deficits or droughts are the most common, afflicting almost 68% of cultivated area in India. The majority of cereals, millets and vegetable crops are grown in poorly water-retentive and less fertile soils in drought-affected regions. To overcome these constraints, farmers heavily depend on limited irrigation water supplies, genetic, agronomic and engineering practices. These include transplanting seedlings or grafted rootstocks in tilled soil bed, using fertilizer and drip irrigation, employing polyethylene mulches, and cultivating stress tolerance varieties, those aimed to enhance soil moisture retention and improve crop performance but not yielded expected benefits in terms of production and quality.

Improved Technology: Integrating plant bio-regulators (PBRs) to promote low external input and sustainable agriculture (LEISA)-based agricultural systems under drought situations seems to be a realistic alternative, especially for resource-poor farmers. PBRs improve nutrient uptake, nutrient use efficiency of fertilizers and impart stress tolerance by regulating physiological processes, plant-water relations and inducing antioxidant defence mechanisms. Therefore, PBR serves as a powerful tool for enhancing productivity, quality and ultimately the net farmers' income.

Performance: Based on field experiments undertaken at ICAR-NIASM so far, following crop/stage-specific recommendations are emerging with respect to the doses and frequencies of PBRs.

Impacts and Upscaling: PBRs are vital for sustaining crop productivity and mitigating water stress in drought-prone areas. Despite their crop and environment specificity, they enhance yield, water productivity, and crop nutritional quality. The economically viable costs of PBR applications make them advantageous. In most tested crops, the water saved equals two irrigations, contributing to normal yields. Overall, integrating PBRs with deficit irrigation (DI) not only boosts farmer productivity and profitability but also aids in extending irrigated areas, particularly in water-scarce conditions. The intervention has been disseminated to over 1800 farmers, entrepreneurs, KVKs, state department extension functionaries, and students through 75 frontline demonstrations, state-level workshops, and training programs.

Crop	PBRs, application rate and growing stages for foliar spray	Improvement in yield (%)	Water productivity (kg m^{-3})
Wheat (cv. HD 2189) 	Thio-urea (10 mM L^{-1}) Growing stages: (DAS) • Crown root initiation (20) • Flag leaf (42–45) • Seed milking stages (65)	5.9-20.6	1.20-1.35
Sorghum (cv. Phule Suchitra) 	Sodium benzoate (100 mg L^{-1}) Growing stages: (DAS) • Seedling elongation (20–25) • Reproductive (50) • Panicle formation (75)	6.8-18.5	1.16-1.41
Soybean (cv. JS–335) 	Salicylic acid (10µM L^{-1}) Growing stages: (DAS) • Flowering stage (35) • Gain formation (55)	4.2-14.2	1.02-1.12
Onion (cv.Bhima Kiran) 	Potassium Nitrate (100 mg L^{-1}) Growing stages: (Days after transplanting) • Vegetative (40) • Bulb formation (60) • Bulb development (80) • Post development (100)	10.1-25	7.8-9.6
Eggplant (cv. Panchganga) 	Salicylic acid (10µM L^{-1}) Growing stages: (Days after Transplanting) • 40 • 65 • 95	6.2-20.9	3.1-6.1
Okra (cv. Singham) 	Irradiated chitosan (5ml L^{-1}) Growing stages: • Vegetative • Flowering • Pod development	6.1–19.2	3.4–3.8

Technology Number: 07

Brinjal grafting technology: Yield enhancement in abiotic and biotic stress conditions

PS Khapte, Sushil S Changan, DD Nangare

School of Drought Stress Management

Recommendation Domain: In the brinjal-producing regions of India, particularly in the semi-arid areas of the Deccan Plateau, it is recommended to promote the adoption of grafting techniques using *Solanum torvum* (NIASM SMR/Karha Kavach) rootstock.

Existing Practise: Currently, farmers use non-grafted brinjal seedlings for cultivation, but these are highly vulnerable to water deficit conditions and soil-borne pathogens, leading to reduced yields, especially in semi-arid regions of the country.

Improved Technology: The use of brinjal grafted seedlings on *Solanum torvum* (NIASM SMR) rootstock has been shown to improve fruit yield in both well-watered (100% ETc) and water deficit (60% ETc) conditions compared to non-grafted scion variety. This rootstock, specifically selected after screening for water stress conditions, demonstrates the capability to enhance growth, branching and yields under both well-watered and water deficit conditions.

Performance: Grafting brinjal onto *Solanum torvum* (NIASM SMR) rootstocks leads to improved growth, increased branching, and a higher number of fruits, ultimately resulting in a higher total fruit yield. In well-watered conditions, the grafted plant produced 106 fruits, while under water deficit, it yielded 97 fruits. In contrast, the non-grafted plant produced only 97 fruits in well-watered conditions and 83 fruits under water deficit. In water-deficit conditions, the grafted brinjal exhibited a 22% increase in fruit yield, while under well-watered conditions, the increase was 14% compared to the non-grafted variety, which yielded 3.2 kg plant^{-1} in water deficit and 4.2 kg plant^{-1} in well-watered conditions.

Impacts and Upscaling: The adoption of grafted brinjal technology using *Solanum torvum* (NIASM SMR) rootstock has the potential to increase net profit by Rs. 42,608 ha^{-1} (1:2.4) in water deficit conditions and Rs. 33,385 ha^{-1} (1:2.9) in well-watered conditions compared to non-grafted. Moreover, the expansion of this technology can be achieved through KVK, ATMA, state line departments, and by establishing connections with private nurseries for further dissemination of this technology.

Technology Number: 08

Multifunctional Ratoon Drill (MRD) for improving productivity of conservation agriculture in sugarcane system

GC Wakchaure

School of Drought Stress Management

Recommendation Domain: Basaltic soil tropical regions including Deccan Plateau (Maharashtra, Karnataka, Gujarat, Western Madhya Pradesh, Chhattisgarh, North-Western Andhra Pradesh, Tamil Nadu)

Existing Practice: Ratoon sugarcane covers half of India's sugarcane area (2.5 Mha), with tropical states in Deccan Plateau regions contributing 40% of total production. Here, managing the high load (10-15 t ha^{-1}) and tough trash after harvest is a challenge for conservation agriculture (CA). This also impedes field operations and intercropping, leading to common practice of trash burning by farmers, causing loss of organic carbon, nutrients, and soil biota and 25–30% reduction in ratoon cane yield compared to fresh crops. This practice also results in environmental pollution and health hazards.

Improved Technology: MRD is a tractor (35–60 hp) operated, driven by PTO equipment and has provision to mount on a three-point hitch linkages system. In addition to drilling of fertilizers (15–20 cm depth) and seeds of intercrop (5–7 cm) to soil; the equipment was found suitable to perform other operations viz., trash chopping, stubble shaving, covering of trash with loose soil, off-barring, and root pruning in a single go under chopped trash retained sugarcane ratoon crop. The checking soil moisture in field, removal drip pipes, calibration for fertiliser/seed rate, and adjusting the spacing between off-bar and depth of shovels/tines at the time of use is essential. The cost of MRD machine is ₹ 1 lakh with all accessories.

Performance: MRD improved ratoon sugarcane yields (10–38%), nitrogen use efficiency (14%) and helped in saving 12–21% irrigation water and 20–25% fertiliser requirement of ratoon crop. This practice also reduced ammonia volatilization losses and N_2O emissions. Further, significant enhancement in yield responses of chickpea and summer maize as an intercrop was noticed in ratoon sugarcane. The field capacity MRD is 0.60 ha h^{-1} using a 35 hp tractor at 3.2 km h^{-1} operational speed with 95% efficiency. This translates B:C ratio to 1.6–1.8 in ratoon sugarcane over conventional farmer's practices and thereby increased net profit up to INR 50000 ha^{-1}.

Ratoon sugarcane cultivation using conservation agriculture and conventional farmers practices

Impacts and Upscaling: This technology offers a practical and economic solution to implement the conservation agricultural practices in the trash-retained ratoon sugarcane field, thereby solving the trash-burning problem in sugarcane cultivation to improve the soil health and environmental quality. Keeping in mind around 2.5 M ha area under ratoon crop, it is estimated that approximately Rs. 6.75–12.50 thousand crore/annum could be earned as an additional net profit by the farmers using MRD equipment. This technology was disseminated to more than 2000 sugarcane farmers, entrepreneurs KVKs, and State Department extension functionaries through 300 on-farm field experiments, demonstrations, and training programs organized by ICAR–NIASM, Baramati.

Technology Number: 09

Residue and nutrient management strategies for improved yield, soil organic carbon and soil biology in multi-ratoon sugarcane

Aliza Pradhan, GC Wakchaure, Dhanashri Shid, PS Minhas, AK Biswas, K Sammi Reddy

School of Drought Stress Management

Recommendation Domain: Black soils of Pune, Nashik, Aurangabad divisions of Maharashtra

Existing Practice: A normal yielding sugarcane crop produces (8-10) t ha^{-1} of recyclable residues in the form of dried leaves (trash), which are essential for maintaining soil organic carbon (SOC). However, residue burning either before or after sugarcane harvest is a common practice among farmers, which not only results in losses of surface organic matter, SOC, essential nutrients, soil enzymatic activities, and soil microorganisms but also causes environmental pollution.

Improved Technology: Retention of sugarcane residue (RR) along with application of 50% of the recommended dose of fertilizers (RDF *i.e.* 300:150:150 kg N, P_2O_5 & K_2O kg ha^{-1}) through stubble shaver, off-bar, root pruner cum fertilizer drill (SORF) as basal followed by rest 50% RDF in subsequent fertigations in ratoon crop is recommended for higher soil carbon, soil biology and crop yield in black soils.

Performance: In ratoon crop, residue retention with 50% application of RDF as basal in band placement through SORF and remaining 50% RDF through fertigation improved the highest ratoon cane yields by 83% over farmers' practice (84.8 t ha^{-1}). The treatment also had a B: C ratio of 2.96 in ratoon sugarcane, which was significantly higher as compared to conventional practice (1.89). Further, residue retention plots had 21% higher total SOC than residue burning plots (21.9 t C ha^{-1}) in upper 30 cm soil. Significantly higher dehydrogenase activity (DHA) (86%), alkaline phosphatase activity (APA) (16%), and ß-glucosidase activity (BGA) (22%) were observed in RR plots as compared to residue burning plots. Microbial counts (population of bacteria, fungi, and actinomycetes) also followed the same trend as that of enzyme activities. Residue retention practices reported higher C sequestration (0.68 t C ha^{-1} yr^{-1}), and carbon retention efficiency (37%), with a potential to reduce greenhouse gas emissions by 2.72 t CO_2 ha^{-1} yr^{-1} as compared to traditional practices.

Impacts and Upscaling: The adoption of residue retention and proper nutrient management has the potential to achieve a B: C ratio of 2.96, significantly higher as compared to conventional practice of 1.89. Further, the practices have the potential for long-term sustainability of sugarcane cultivation (in an area of 27 M ha including India) in view of declining soil fertility and forecasted global warming with climate change.

Technology Number: 10

Cultivation of Kharif Chickpea: A novel practice for raising farmers' income in Western Maharashtra

Gurumurthy S, KR Soren, Mahesh Kumar, Boraiah KM, Jagadish Rane, Himanshu Pathak

School of Drought Stress Management

Recommendation Domain: Low rainfall areas of Western Maharashtra.

Improved Technology: Chickpea is cultivated in India typically during the rabi season from October to February. However, some regions in western Maharashtra show promising potential for *Kharif* season cultivation (June-August) due to favourable weather conditions. The area experiences an average temperature of 20-30°C and 200-250 mm of rainfall during this period, complemented by well-drained murram soils that maintain optimal moisture levels. These conditions greatly support chickpea flowering and pod formation during *Kharif*, highlighting the critical role of suitable rainfall and temperature for optimum vegetative and reproductive crop growth. Moreover, extensive screening of chickpea germplasm has identified several promising genotypes-IPC06-11, ICE 15654-A, JG-11, Vishal, JG-16, ICCV 92944, JG-14, ICC 4958, and Vijay that exhibit potential for cultivation in these conditions. Studies demonstrate that *Kharif*-grown chickpeas can be harvested within 60-70 days, under moderate or low-intensity rains, with expected yields of raw green pods ranging from 3.0-3.5 t ha^{-1} and grain yields from 0.8 to 0.9 t ha^{-1} showing substantial promise.

Products of Kharif chickpea:

a-green chickpea plant, b- raw green chickpea pods, c- raw tender green chickpea of 60 days old

Potential: Thus, *Kharif* cultivation may offer advantages such as increased yield and income in a shorter duration. Furthermore, it supports seed production and accelerates generation advancement by identifying alternative seed production areas and off-season nurseries, presenting a compelling case for exploring chickpea cultivation during the *Kharif* season.

Impacts and Upscaling: Green bold seeds of chickpea can be a good source of vegetables in *Kharif*. They can be utilized as snacks in both fresh and roasted forms, offering income opportunities for farmers. The crop is suitable for intercropping in sugarcane and pomegranate fields. Some *Kharif* chickpea varieties have a shorter maturation period of 60-70 days under rainfed conditions, reducing cultivation costs by minimizing the need for weeding, irrigation, and pesticides. This technology has been shared with over 100 sugarcane farmers, entrepreneurs, KVKs, and State Department extension officials through 300 on-farm experiments, demonstrations, and training programmes.

Technology Number: 11

Chia-based intercropping model with vegetables for higher profitability

Harisha CB, Jagadish Rane, HM Halli, Boraiah KM, Basavaraj PS

School of Edaphic Stress Management

Recommendation Domain: Nashik, Chinchwad, Pune, Thane, Amaravati, Nagpur, Beed, Hingoli, Jalna, Latur, Nanded, Osmanabad and Parbhani regions of Maharashtra

Existing Practice: Chia is being cultivated as a sole crop with a wider spacing of 60 cm to 90 cm between rows. The planting season for this crop is from August to October, specifically in red and medium-black soils. The wider spacing between rows makes the land vacant for initial 30 days after sowing. This space is very much amenable for intercropping of short-duration leafy vegetables.

Improved Technology: Cultivating fenugreek for its leaves in the gaps between chia plants, maintaining a row ratio of 1:2, proves to be a cost-effective approach in well-irrigated and deficit-irrigated conditions (50%). Principal crop (Chia) is sown with a row spacing of 60cm, while fenugreek seeds (40 kg.ha^{-1}) are sown in the interspaces at 30 cm row spacing. Nutrient doses of 190:90:70 kg N, P_2O_5 and K_2O may be applied for both chia and fenugreek. At 15 days after sowing (DAS), a top dressing of 50 kg N is recommended. The remaining 50 kg N can be applied after the harvest of fenugreek. Crop can be raised in drip irrigation system.

Performance: The chia+ fenugreek system yields 628 kg ha^{-1} of seed and 4685 kg ha^{-1} of green fenugreek. The chia equivalent yield of chia+fenugreek system was 1106 kg.ha^{-1} compared to chia sole crop yield of 706 kg ha^{-1}. In 50% deficit irrigation, the equivalent yield of chia+fenugreek system is 813.5 kg.ha^{-1} which is comparable to chia monocrop in 100% irrigation. Chia fenugreek realized net returns of Rs.1,07,000 ha^{-1} and Rs.75,000 ha^{-1} with BC ratio of 2.89 and 2.45 in 100% and 50% irrigation, respectively. Whereas, chia monocrop realized Rs. 74,000 ha^{-1} and Rs. 53,000 ha^{-1} with BC ratio of 2.58 and 2.25 in 100% and 50% irrigation respectively. Therefore growing chia + fenugreek is economical in both deficit and well-irrigated conditions.

Chia+fenugreek intercrop and Chia sole crop

Impacts and Upscaling: Adopting intercropping in Chia helps for diversified income generating avenues. This technology can be adopted in all chia-growing areas of Maharashtra by demonstration through KVKs, state departments, ATMA, SAU, NGOs, etc.

Technology Number: 12

Climate resilient integrated farming system model for enhancing productivity and livelihood improvement of farmers in semi-arid regions

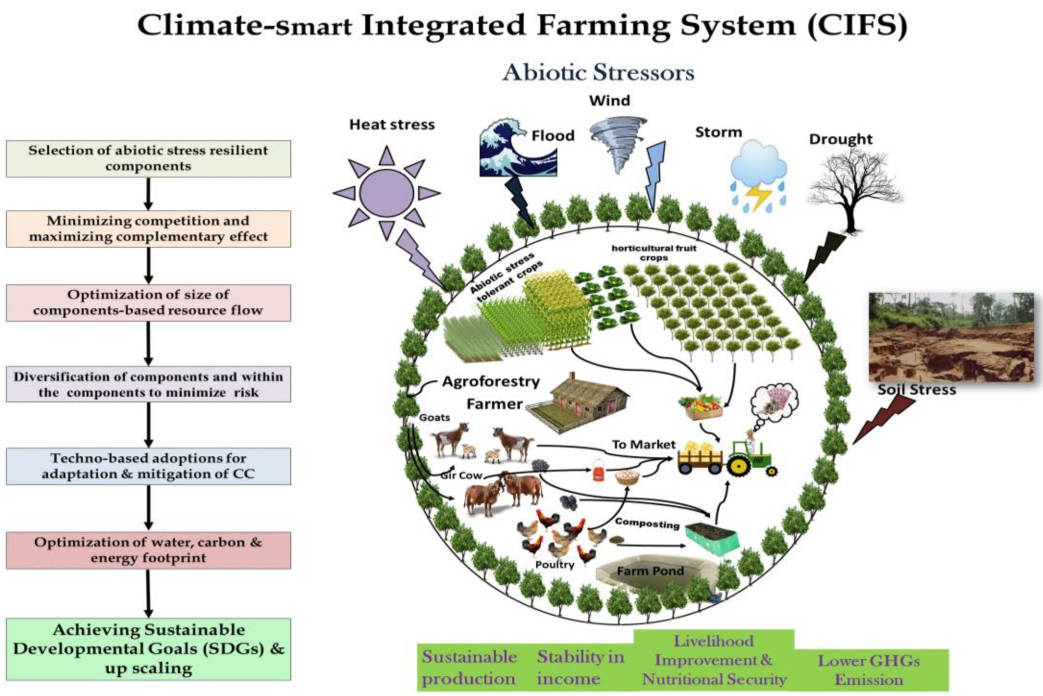
SA Kochewad, Aliza Pradhan, Vanita S Salunkhe, SB Chavan, GC Wakchaure, Vijaysinha D Kakade, Neeraj Kumar, V Rajagopal, B Rajkumar, HM Halli, LR Meena, N Subash, K Ravi Kumar, B Gopalkrishna, Pravin Taware, P Chahande, K Sammi Reddy

School of Edaphic Stress Management

Recommendation Domain: Recommended for dry semi-arid regions with an annual rainfall ranging between 500-750 mm and a crop growing period of 90-120 days, which covers 41.6 million hectares. These regions have loamy sand, light sandy loam, and medium black soils in the northern part, while the southern parts are characterized by medium to black soils.

Existing Practice: Crop cultivation in most semi-arid regions is limited to the rainy season. Agriculture in these areas relies heavily on rainwater, and major crops include pearl millet, sorghum, maize, cotton, soybean, groundnut, and pulses. Livestock, such as cattle, sheep, and goats, are essential supplementary occupations. Plantation crops are cultivated in areas with irrigation facilities. Additionally, during the summer, there is a practice of allowing livestock to graze freely in cultivated areas in some regions.

Improved Technology: The agricultural production system in semi-arid regions must prioritize sustainability and resilience, encompassing higher productivity, risk reduction, and lower greenhouse gas emissions. To address these challenges, a climate-resilient integrated farming system (CIFS) has been developed at ICAR-NIASM in Baramati. This innovative system involves diversifying farming components both within and across different areas, optimizing their size, and leveraging climate-smart technologies to minimize risks, ensuring sustainable production and income amidst changing climatic conditions. The components of CIFS model include Crop cultivation spanning 6250 m^2, Horticulture across 3000 sq. m., Livestock with indigenous cows (02), goats (10), native poultry birds (50), fisheries covering 400 m^2., and agroforestry through boundary plantations.



Performance: In the crop component, the total cultivation cost amounted to Rs. 38,017, yielding a gross income of Rs. 51,699 and a net income of Rs. 13,681, resulting in an overall benefit-cost (B:C) ratio of 1.35. Transitioning to the livestock component, the total rearing cost was Rs. 235,857, generating a gross income of Rs. 309,478 and a net return of Rs. 73,621, with a B:C ratio of 1.31. For the horticulture component, the cultivation cost was Rs. 8,388, leading to a gross income of Rs. 17,932 and a net return of Rs. 9,543, resulting in a B:C ratio of 2.13. Considering the entire CIFS model, the overall cultivation cost, gross income, and net returns were Rs. 282,262, Rs. 379,109, and Rs. 96,845, respectively. The cumulative B:C ratio for the CIFS model was 1.34.

Impacts and Upscaling: The research experiences gathered over the years have consistently demonstrated that CIFS contribute to increased diversification, intensification, enhanced natural resource use efficiency, improved productivity, and overall sustainability. The developed climate-resilient integrated farming system has been effectively demonstrated to more than 3000 stakeholders, including small and marginal farmers, progressive farmers, students, and researchers visiting our institute. Furthermore, practical demonstrations have been conducted on farmers' fields. Crucially, farmers' active participation in the design, evaluation, and refinement of farming systems research is deemed essential for the successful adoption of CIFS.

Technology Number: 13

Nano-materials for growth improvement in aquaculture against multiple abiotic stresses

Neeraj Kumar, Paritosh Kumar, SA Kochewad, K Sammi Reddy

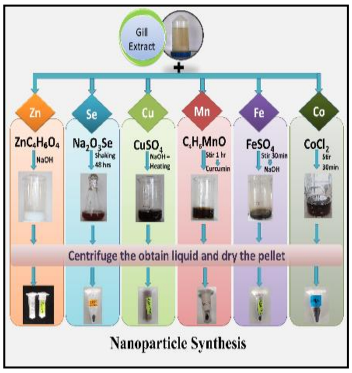
School of Edaphic Stress Management

Recommendation Domain: Freshwater aquaculture, Brackish water Aquaculture and Marine water aquaculture

Existing Practices: Until now, no specific mineral mixture has been formulated for aquaculture and fisheries. Instead, mineral mixtures designed for veterinary purposes have been applied in fisheries. Resulting in higher bio-accumulation of harmful nutrients in the muscle tissues of fish, posing a subsequent risk to human health upon consumption of these fishes.

New Invention: The present product based on nano-mineral is specifically developed for fish and recommended in specified doses in fish feed. This not only improves the growth performance of the fish but also safeguards consumers from potential health risks. The present invention relates to animal feed supplements in the nano-form that improves the productive preformation including growth factors of aquatic animals reared in control (stress-free) or under stressful conditions.

S. No.	Nano-nutrient	Dose/ ton of feed
1	Zinc nanoparticles (Zn-NPs)	1 gram
2	Selenium nanoparticles (Se-NPs)	200 mg
3	Copper Nanoparticles (Cu-NPs)	500 mg
4	Manganese nanoparticles (Mn-NPs)	200 mg
5	Cobalt nanoparticles (Co-NPs)	100 mg
6	Iron nanoparticles (Fe-NPs)	10 gram



Feed prepared with Nano-material

Impacts and Performance: It is a nano-mineral mixture containing zinc nanoparticles (Zn-NPs), selenium nanoparticles (Se-NPs), manganese nanoparticles (Mn-NPs), copper nanoparticles (Cu-NPs), cobalt nanoparticles (Co-NPs) and Iron nanoparticles (Fe-NPs), which improves growth (109%) and feed conversion (101%) in fish reared under control (stress-free) or under stressful conditions. It is also beneficial for improving anti-oxidative status, reproductive hormones, immunity, survival and protection against pathological infection. It also improves the flesh quality and reduces the bioaccumulation of contaminants in fish bodies which reduces human health risk.

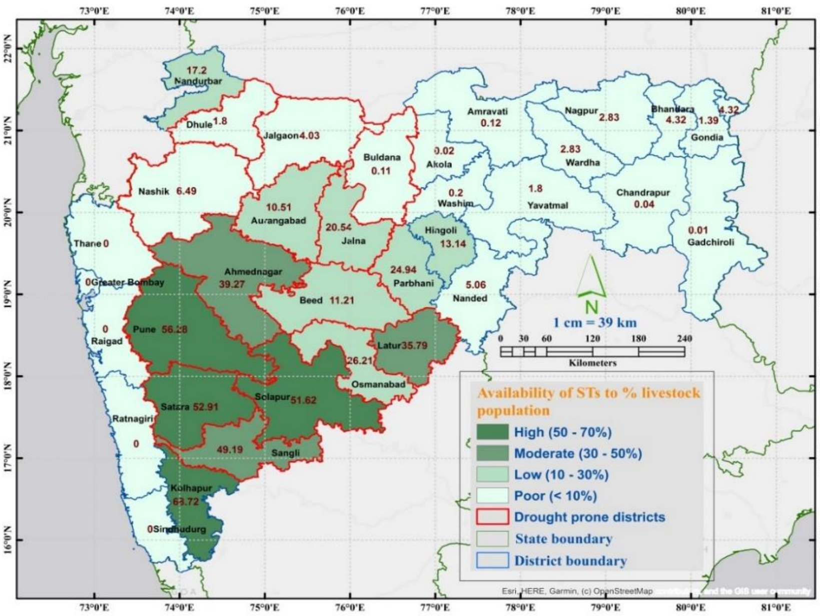
Technology Number: 14

Mixed silage of sugarcane tops for improving nutrition and fodder availability of livestock in drought-prone areas

NP Kurade, SS Pawar, BB Gaikwad, B Gopalakrishnan, SA Gade, MP Brahmane, PL Chavan, AV Nirmale, Neeraj Kumar, K Sammi Reddy

School of Atmospheric Stress Management

Recommendation Domain: Sugarcane-producing areas of western Maharashtra overlapping with drought-prone areas (Fig. 1), may benefit from the recommended practice of mixed silage of sugarcane tops (STs).



Availability of STs either as green fodder (during Oct-Mar) or mixed silage (across the year) to the percent of livestock in drought-prone and other districts of Maharashtra

Existing Practice: Livestock requires a balanced diet with high-quality forages to meet their nutritional requirements. However, most of the livestock from sugarcane growing areas are fed sugarcane tops as a major portion or sole source of fodder. Sole feeding of STs is not a good practice for livestock health, production, and reproduction. During scarcity periods, whole sugarcane crops are being fed to livestock for their sustenance. This has been observed commonly in cattle camps during drought periods. The nutritive value of STs is highly variable and depends on management practices, stalk cutting point, plant maturity, and the number of dry leaves. Animals meet their maintenance energy needs by consuming STs as the sole ingredient of their rations, but in due course, they either lose condition, barely maintain themselves, or at best, have very low production levels.

Improved Technology: As an effort to foster a more effective utilization of available resources and to avoid the generation of potential pollutants, which could contribute to cleaner, greener, and more sustainable livestock production, mixed silage using up to 50% of STs has been developed. Preparation of mixed silage of sugarcane tops with fodder jowar or maize fodder helps in increasing fodder availability. This also helps to reduce the exposure of livestock to the sole feeding of STs.


Mix silage of sugarcane tops and feeding to animals

Performance: The performance of mixed silage of STs at 25, 50, 75, and 100% levels with jowar fodder was evaluated in lactating buffaloes. Based on the physical evaluation and feeding trial, it was found that mixed silage of sugarcane tops up to 50% level may be used for sustaining milk production in lactating animals during scarcity periods.

Impacts and Upscaling: This technology is routinely used in institute farms successfully. Technology demonstrations to many dairy farmer groups were carried out on the institute farm. The farmers in nearby areas have adapted this practice to improve nutrition and availability of fodder for their livestock. Self-help groups of farmers can utilize this practice to generate income by using suitable machinery available in the market. STs Availability (225 lakh tonnes) is higher in most of the drought-prone areas of Maharashtra where the livestock density is also higher. Mixed silage of ST has the potential to fulfill the green fodder requirement of up to 68.7% of the livestock population during scarcity periods and up to 30.7% in drought-prone areas.

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Technology Number: 15

NIASM-designed constructed wetland and integrated aquaponics for wastewater treatment and simultaneous cultivation of marigold, spinach and fish

Paritosh Kumar, Neeraj Kumar, Harisha CB

School of Edaphic Stress Management

Recommended domain: Anywhere having wastewater availability mostly in urban, peri-urban and village areas of India

Existing practices: Many farmers irrigate sewage wastewater in their fields during freshwater scarcity due to easy, timely, sufficient availability and for fertilizer savings. Without proper treatment, it is unhygienic practice for farmers, unsafe/nonedible agricultural produce causes many diseases and cancer in humans, and affects environment to beneficial insects, birds, and animals.

Improved Technology: NIASM designed Constructed wetland and integrated aquaponics system is a natural energy-driven decentralized wastewater treatment system configured with locally available media mixture and naturally inhabited microbial consortia or biofilm. This can do treatment/ filtration of wastewater and commercial floriculture simultaneously. Treated water is stored/fed in an aquaponics system where their further polishing/enrichment occurs along with leafy vegetable cultivation and fish rearing. This enriched water now are safe for agricultural reuse as per WHO/FAO/Indian standards and so can be used for growing crops, irrigating roadside plantations, lawn irrigation, kitchen gardening, nursery raising etc.

Constructed wetland with UV treatment

Aquaponics

Performance: The versatile designed wetland system operates at various scales, from small to large, using locally available materials and biofilm. It boasts high removal capacities for pathogens ((faecal coliform and E.coli >95%), organic load (>80%), heavy metals (>90%), and salts). With a 48-hour hydraulic retention time and minimal evapotranspiration losses, it is efficient. Economic yields include 500g of African marigold flowers per plant, 100g of spinach per plant, and a 100% increase in pangasius fish weight in three months. The setup cost is Rs. 2000 for a 100-liter system, with low electricity consumption. It has a lifespan exceeding 10 years with cement and over 5 years with PVC. The compact system requires only 1 square meter for 200 liter.day^{-1} treatment unit, allowing for vertical expansion, and can be operated by less skilled individuals with no sludge disposal problems.

Impacts and Upscaling: This system will help to reduce the burden of wastewater treatment on Sewage Treatment Plants (STPs) and mitigate water scarcity problems in water scare regions, can produce additional profit from the wastewater treatment and may emerge as a business model in urban, peri-urban and village areas. This strategy will also help in improving water quality in rivers, ponds, lakes, oceans, and groundwater, reducing greenhouse gas emissions from wastewater mismanagement; and providing sanitation and hygiene in developing countries for achieving sustainable development goals (SDGs).

Technology Number: 16

Climate Resilient CHARA BANK for round-the-year fodder availability for livestock in drought-prone regions

SB Chavan, BB Gaikwad, AV Nirmale, AS Morade, VD Kakade, SS Pawar, NP Kurade, SA Kochewad, HM Halli, VB Gawade and KS Reddy

School of Edaphic Stress Management

Recommended domain: Theses models are ideal for semi-arid, rain-fed regions of Maharashtra, especially on shallow, degraded and non- arable soils. It performs well under limited moisture conditions but assured irrigation boosts productivity and extends its viability beyond five years.

Existing practices: Indian livestock owners faces a critical fodder shortage, with an estimated annual requirement of 855 million tonnes of green fodder, 526 million tonnes of dry matter,, and 56 million tonnes of concentrates. This demand-suply gap has resulted in a 70% deficit in the dairy sector, leading to reduced milk production and lower farmers' incomes. In Maharashtra, shortfalls of 31.3% (dry) and 59.4% (green) fodder further exacerbate this issue. With shrinking grazing lands and the current practices of reliance on crop residues, sugarcane tops, fodder maize, dry sorghum and grazing are unsustainable. Excessive dependency on concentrate feeding increases cost and causes livestock health issues. There is an urgent need for year-round, cost-effective fodder production systems.

Improved Technology: A 1000 m² Leucaena-based perennial CHARA bank is an intensive, multilayer silvipasture model designed to provide protein-rich green fodder throughtout the year. It integrates drought-tolerant species such as *Leucaena leucocephala*, *Desmanthus virgatus*, *Cenchrus ciliaris*, and *Sesbania grandiflora*. Leucaena is planted in a north–south direction at 10 ft × 7 ft spacing, using either direct seeding or transplanting 6–7-week-old seedlings to accomodate 140-150 seedlings. *Cenchrus* is sown in rows spaced 50 × 50 cm spacing, and *Desmanthus* at 30 × 30 cm. *Sesbania* is planted along boundaries at 7–10 ft spacing (40-50 plants on boundaries). Apply 2 tonnes of FYM and 10:25:10 kg NPK per 1000 m², splitting nitrogen into two doses. Irrigation is given during dry spells of Monsoon, at fortnight interval in winter, and weekly interval in summer during first year. Second year onwards, drip irrigation (4 litres/hour for 8 hours/day) is recommended.

A 1000 m² Leucaena-based perennial CHARA bank model for round-the-year fodder production in drought-prone regions

Performance: Leucaena-based perennial CHARA bank provides the green and poretin rich fodder at every 50-60 days. For trees like *Leucaena* and *Sesbania*, give the first heading back 5–6 months after sowing, at 75–100 cm above ground. For grasses like *Cenchrus* and *Dasharath*, the first cut can be taken 70–80 days after planting. *Leucaena* provides 2–3 kg of green fodder per tree in the first year, increasing in later years. *Sesbania* yileds 2–3 kg leaves per plant. In a 1000 m^2 model, *Leucaena* yields 1–1.5 tonnes and *Sesbania* 300–400 kg per year. *Cenchrus* grass produces around 3 tonnes, and *Dasharath* (Hedge Lucerne) gives about 4 tonnes from 500 sq m each. Overall, this multi-tier model produces about 8–8.5 tonnes of green fodder annually from 1000 m^2. Even in drought conditions, it can yield at least 50% of the normal output and can last 4–5 years with proper water and nutrient management. With good water, nutrients, and care, fodder growth and cutting frequency improves significantly.

Impacts and Upscaling: The Leucaena-based multi-tier CHARA bank model, established on 1000 m^2, involves an initial investment of approximately ₹21,594, covering seeds, manure, fertilizers, drip irrigation, and labour. It yields around 9.0 tonnes of green fodder annually. At ₹4/kg market price, the gross income is ₹35,600, with a net profit of ₹14,006 and a benefit-cost ratio of 1.65—making it a viable and profitable option for smallholders. Protein-rich tree fodder in this model helps to reduce methane emissions, enhances milk yield by 10–15%, and cuts concentrated feed use by 25–50%, improving livestock health and resilience to climate stress. This model has been demonstrated to over 250 dairy farmers, entrepreneurs, KVKs, state extension staff, students, and NABARD officials. With NABARD Pune's support, it is being implemented on 21 farmer fields and further promoted through training and demonstrations at ICAR-NIASM, Baramati.

Technology Number: 17

Strategic pruning for enhancing productivity of Dragon fruit in multi-stressed regions

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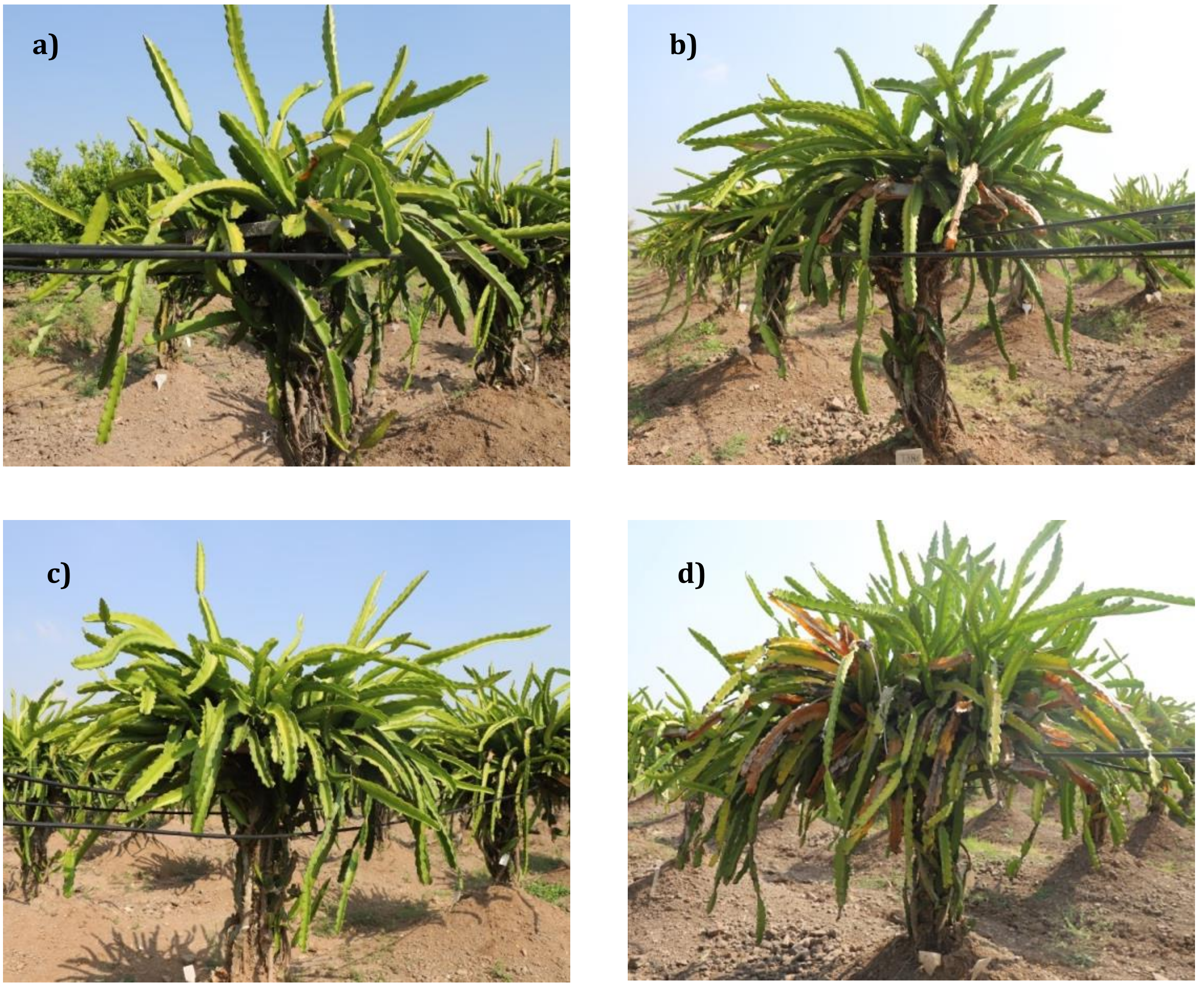
School of Edaphic Stress Management

Recommended domain: Dragon fruit cultivation is predominant in semi-arid, hot and dry regions of Maharashtra, Gujarat, Karnataka, Tamil Nadu, Andhra Pradesh, and Telangana. The semi-arid regions in these states often experience summer temperatures that surpass 35 °C, less rainfall (<800 mm) and high evapo-transpiration rates, posing challenges for farmers for fruitful growth. This technology is applicable in these regions to balance vegetative growth, fruit yield and quality in orchards grown under rocky basaltic soils and water-heat stress environments.

Existing practices: The presence of spines, large cladodes, and limited farmer awareness make pruning in dragon fruit cultivation a challenging task. This results in canopy crowding with approximately 300 cladodes per pole over time. During the initial years of dragon fruit introduction in India, the demand for planting material remained high until around 2023. To meet this demand, farmers frequently pruned their plants to produce propagation material, which inadvertently helped maintain an optimum number of cladodes per plant. However, with the recent decline in planting material demand, pruning practices have reduced significantly. As a result, farmers are no longer maintaining proper canopy structure, leading to excessive cladode accumulation and overcrowding as plantations age.

Improved Technology: We evaluated impact of different levels of strategic pruning (light: 121-160; moderate: 81-120; and severe: 40-80 cladodes per pole) on growth, fruit yield and quality in plants grown under rocky basaltic soils and water-heat stress environments during 2022 and 2023. Based on the findings, we recommend maintaining 120–160 cladodes per pole or 12–14 cladodes per square meter area under a mop-top training system through need-based light pruning for semi-arid regions to improve productivity and reduce stress-related losses. The best pruning time is November–December, ensuring sprouting and sufficient time for new cladode growth before flowering. Therefore, in mop-top systems, light pruning in every 1-2 years and heavy pruning every 4–5 years are recommended. Healthy cuttings should be used for propagation, while infected ones must be isolated and shredded in designated areas to prevent pathogen spread. Non-infected, unused biomass can be shredded and added to the soil. Pruning tools should be disinfected with alcohol or hydrogen peroxide throughout the process. Spraying the cut ends and injured part with Bordeaux mixture @ 1 % or Mancozeb + Carbendazim @ 2.5 % or Copper oxychloride @ 3 % or Propineb @ 2 % is recommended immediately after pruning to prevent the secondary fungal infection.

Performance: In light pruning, yield was increased from 23 to 30 tons/ha, whereas in unpruned plants it was increased from 28 to 29 tons/ha. Light to moderate pruning resulted in 11–48% yield improvement in the second year, while control plants showed only a 2.8% increase. Fruit weight increased significantly (338–410 g) compared to 305–310 g in unpruned plants. Pruning reduced disease incidence (stem canker and rot) up to 81.51%. In lightly pruned plants disease incidence was 11-15% compared to 27-41% in unpruned plants. Pruning also minimized sunburn incidence to the tune of 12-15% over 40-47% in unpruned plants. Pruning notably promoted new sprouts and fruit bearing cladode production. Light pruning showed the highest emergence of new sprouts (25.67 and 23.33), while unpruned plants had the lowest (8.00).



Comparison of plant canopies and disease incidence in different pruning treatments a) severe, b) moderate, c) light and d) un-pruned control

Impacts and Upscaling: This technology is being disseminated through TV talks, workshops, seminars, and social media programs. The pruning technology demonstrates excellent cost-effectiveness, with a benefit-cost ratio of 3.47 compared to 2.60 in unpruned controls. This indicates higher economic returns for growers due to yield gains, reduced input costs for disease and sunburn management, and improved overall productivity. This technology is unique because it provides the climate- and soil-specific canopy management recommendation tailored for dragon fruit cultivation in semi-arid regions. Unlike previous pruning guidelines developed for humid tropical climates, it recognizes the distinct challenges of heat, water scarcity, and high solar radiation in dry environments.

Technology Number: 18

Wider pit and trench planting techniques: Enhancing fruit production and quality on shallow rocky barren lands

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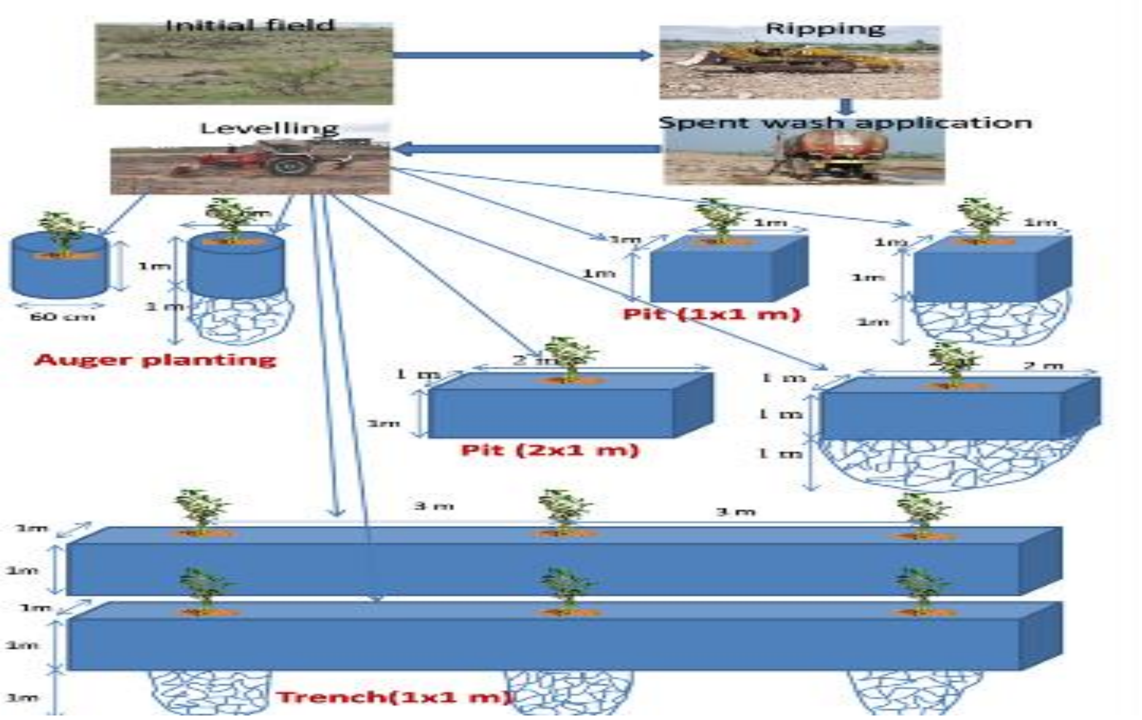
Recommended domain: This technology is recommended for regions characterized by barren, rocky lands with murrum-type soils. These areas typically have shallow soil depths of less than 60 cm, with fine earth content ranging from 22% to 35% (w/w), while the remaining portion consists of coarse fragments of varying sizes. Such land types are widespread, covering approximately 26.5 million hectares across the Deccan region of India.

Existing practices: Due to poor water-holding capacity and minimal soil cover, these lands are generally unsuitable for conventional crop cultivation. In an effort to utilize these marginal areas, farmers have shifted to pomegranate cultivation. However, establishing tree seedlings on such terrain is highly challenging. Most farmers adopt the practice of planting in small conventional pits of just 0.06 m^3, often surrounded by loose boulders scattered across the rocky surface. This inadequate planting method has resulted in serious issues, including high seedling mortality, poor plant establishment, low fruit yields, and inferior fruit quality.

Improved Technology: An improved planting method involving wider and trench-shaped pits of 2–3 m^3 capacity, specifically designed for pomegranate cultivation on shallow, gravelly lands. These pits are filled with a 1:1 mixture of native soil (typically sandy clay loam) and black soil (clay), resulting in a composite clay loam texture that offers better water-holding capacity and nutrient retention. The resulting soil mixture has a bulk density ranging from 1.27 to 1.32 Mg m^{-3}. To fill each pit, the soil requirement is approximately 2.54–2.64 Mg for 2 m^3 pits and 3.81–3.96 Mg for 3 m^3 pits, depending on the compaction and moisture content. This method significantly enhances root growth, tree establishment, and long-term yield performance under challenging soil conditions.



Pictorial of different planting methods

Rocky barren land with murrum soil

Making of wider trench planting pits

Enhanced growth & development under the improved wider pit planting method

Trench pit planting of young trees &filling of soil

Pomegranate cultivation in rocky, shallow barren land for enhancing land productivity & fruit quality

Performance: The adoption of trench and wider pit planting methods (2–3 m^3) for pomegranate cultivation on shallow and gravelly barren lands has shown significant agronomic and economic benefits, as demonstrated in long-term field trials at ICAR-NIASM. This approach has proven to be a viable and scalable technology for dryland horticulture. Agronomically, it enhances fruit yield by 35–60%, with recorded yields ranging from 7.3 to 8.0 t/ha—substantially higher than the 4.0–5.5 t ha^{-1} typically achieved through conventional farmer practices. Fruit quality has also improved notably, with average fruit weights, total soluble solids (TSS) ranging from 15.0 to 16.2 °Brix, and higher juice content, all contributing to improved market value. These gains are attributed to improved soil structure, deeper and more vigorous root development, better moisture retention, and enhanced nutrient use efficiency made possible by the larger pit volume and the use of a 1:1 mixture of native soil and black soil.

Impacts and Upscaling: The economic advantage of adopting these improved planting methods is substantial. At a market price of ₹250 per kilogram, trench planting yields a gross income of approximately ₹19.93 lakh per hectare, while the wider pit method generates around ₹18.03 lakh per hectare. In contrast, conventional farmer practices yield only about ₹12.90 lakh per hectare. This translates into an additional income of ₹7.03 lakh per hectare through trench planting and ₹5.13 lakh per hectare through wider pit planting—primarily due to improved fruit quality and yield stability, especially under the moisture-stressed conditions typical of semi-arid regions.

This technology is highly suitable for upscaling in semi-arid zones of Maharashtra, Karnataka, Telangana, Gujarat, and Rajasthan, where shallow soils and high gravel content constrain agricultural productivity. It aligns well with government-supported initiatives such as PMKSY, MIDH, and MGNREGA, offering strong potential for convergence funding, input support, and labor deployment for trench preparation. To facilitate large-scale adoption, it is recommended to establish demonstration plots, conduct localized farmer trainings, and promote implementation through Farmer Producer Organizations (FPOs). Overall, trench and wider pit planting methods, coupled with enriched soil mixtures, present a sustainable, climate-resilient solution for converting unproductive, degraded lands into high-yielding and economically viable pomegranate orchards.

Technology Number: 19

Enhancing quinoa (*Chenopodium quinoa* Willd.) yield and sustainability in shallow basaltic semi-arid regions

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Recommended domain: Murram or shallow basaltic soils of Deccan Plateau

Existing practices: Edaphic constraints, such as shallow (26.4 million ha) and low-fertile soils (49.7 million ha), particularly in water-scarce and drought-prone agro-ecologies of peninsular India, highlight the need for alternative crop-based interventions. In this context, encouraging climate-smart, nutritious crop production systems is crucial for providing accessible, affordable, safe, and nutritious diets for communities. Compared to dominant cereals such as rice, wheat, and maize, quinoa (*Chenopodium quinoa* Willd.), an pesudocereal, stands out as a gluten-free pesudocereal rich in protein (13%–17%), well-balanced amino acids, essential vitamins, minerals, and bioactive compounds. Since the United Nations' declaration of the International Year of Quinoa in 2013, there has been a rapid expansion in the cultivated area dedicated to this crop, shifting perceptions and elevating its status from a minor to a potentially major crop. However, to date, there have been limited developments in terms of quinoa's adaptation in India, despite the country's arid and marginal environments.

Improved Technology: Sowing of quinoa in 1st week of November with irrigation at 40% ET_c (around 100 mm) through drip during flowering and grain filling stages and application of 100 kg N ha^{-1} will produce a seed yield of 14 q ha^{-1}, a level of production that most food crops cannot achieve economically in the shallow basaltic rocky terrains of drought-prone environments.

Quinoa crop in shallow basaltic murram soils at ICAR-NIASM, Maharashtra

Performance: In shallow basaltic semi-arid regions, sowing quinoa during 1st week of November enhanced crop biomass, yield, and water productivity as temperatures aligned more closely with optimal quinoa growth conditions. Higher temperatures during critical growth stages, *i.e.*, anthesis and seed filling, and a short growing cycle are among the factors that reduced yield in late November and December sowing. Similarly, water productivity of quinoa was higher under 40% ET_c (0.85 kg m^{-3}) compared to 80% ETc (0.36 kg m^{-3}), confirming its high water use efficiency under moisture deficit conditions. Further, though quinoa responded positively to higher N doses, its application at 100 kg N ha^{-1} was found suitable considering the shallow basaltic rock, root restrictions, limited irrigation, and lodging issues. The recommended package of practice also demonstrated higher carbon efficiency (3.69), lowest carbon footprint (0.19 kg CE kg^{-1} seed) and higher sustainability (CSI, 2.69). The benefit-cost (B:C) ratio of promoting successful cultivation of quinoa in shallow basaltic semi-arid regions was 3.5:1. Overall, the technology highlights quinoa's potential as a promising candidate for crop diversification in India and other countries with similar climatic conditions.

Quinoa crop in shallow basaltic soils at farmer's field in Rajale village, Satara, Maharashtra

Impacts and Upscaling: Quinoa's resilience and superior nutritional profile have positioned it as a promising crop to combat silent hunger and malnutrition while reducing the global food environmental footprint. Given that a substantial portion of the Indian population lacks access to protein rich diets, quinoa's proteinaceous seed could significantly contribute to addressing hunger. However, knowledge about optimal management practices for its cultivation in marginal areas of India is essential and these strategies should be tailored to specific agro-ecological conditions. Furthermore, there is also a need to design a product marketing strategy and raise awareness among farmers and government agencies about quinoa's potential as a stress-tolerant alternative crop for marginal environments. Although the removal of saponin—an anti-nutritional element present in the seed coat of quinoa—was once a tedious process, the availability of small-scale quinoa pearlers has now made it much easier to be adapted by farmers.

Technology Number: 20

Trenching and transforming filled-in soil technology for Dragon fruit

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School of Drought Stress Management

Recommended domain: Shallow basaltic tropical and degraded regions covering 26.4 million hectares, including the Deccan Plateau of India.

Existing practices: Orchard sustainability in shallow basaltic and degraded areas is hindered by water scarcity, low soil fertility, and poor root anchorage, leading to reduced crop productivity, limited diversification, and underdeveloped agricultural markets. Recently, dragon fruit (*Kamalam*) has emerged as a promising crop due to its ease of cultivation, high stress tolerance, and health benefits. Being a climbing, epiphytic cactus plant, it requires support structures such as concrete, wooden posts, or wall columns. Consequently, farmers in these regions have adopted dragon fruit cultivation, primarily using the pit planting method. Concrete poles/ posts with rings, approximately 2 meters in height, are commonly used, buried 40 cm deep into the ground for support. This results in relatively low fruit yield and poor quality with increasing orchard age. Since it is a relatively new crop for such environmental conditions, a proper understanding of managing its plantation seems essential. Further, issues related to adaptation to water deficits and edaphic stresses, postharvest fruit quality, and economic viability must be critically assessed before recommending for large-scale cultivation.

Improved Technology: The orchard was established on shallow basaltic sites in the Deccan Plateau, with degraded *murrum* soils (0.1–0.3 m deep), a relatively steep slope (4%), and sparse vegetation. It was initially ripped and chained 2–3 times with a heavy dozer, followed by micro-blasting of hard patches until the terrace was uniformly levelled. Locally available spent wash was applied to pulverize the gravelly *murrum*. As a virgin soil was porous, stony (26.7% > 2 mm), low in fertility (Organic-C 0.07%, Av-P 0.5 kg ha^{-1}) and poor water retention capacity, a large amount of spent mushroom substrate (250 m ha^{-3}) was added. Trenches (15 m length × 1 m breadth × 0.5 m depth) were excavated with 3.5 m spacing, and additional pits (1 m × 1 m × 0.5 m) were dug parallel to the trenches as a control. The trenches were filled with (i) original native soil (T-Native, loamy sand; clay 10.3%, *murrum* with 26.7% stones (> 2 mm), FC 0.20 cm^3 cm^{-3}, OC 0.17%, Av-N 54.6 kg ha^{-1}, Av-P 1.3 kg ha^{-1}), (ii) black transported soil (T-Black, clay 54.4%, FC 0.42 cm^3 cm^{-3}, OC 0.70%, Av-N 157.1 kg ha^{-1}, Av-P 6.3 kg ha^{-1}), and (iii) a mixture of both soils (T-mixed soil; 1:1 Black: Native). Concrete posts (2.0 m height) were fixed by burying 0.40 m in soil depth, placed 3 m apart in the filled trenches and pits. Four matured saplings (30 cm length) of dragon fruit, slant-cut at base (2–3 cm), treated with 1500 ppm carbendazim fungicide and 5000 ppm Indole-3-butyric acid (IBA) to prevent soil-borne diseases and promote shoot-root development, were planted at each post. At transplanting, each plant received a basal dose of 10–15 kg FYM and 100 g SSP. In the first two years, plants received 300 g N, 200 g P, and 200 g K per plant. Once the orchard got well-established, the recommended doses of 540 g N, 720 g P, and 300 g K per plant were applied in four equal splits with 3-month intervals. The dragon fruit performance under different rooting zones was evaluated based on yield, yield losses, and fruit quality during the fruiting seasons (10 years).

Performance: On average, the highest fruit yield (18.2±1.0 Mg ha^{-1}) was recorded in trench planting with a 1:1 mix of native and black soils (T-mixed), 44% higher than pit planting (12.4±1.2 Mg ha^{-1}). Yield gains were 32.1% in T-black and 13% in T-native soils. Yield losses were reduced by 40%, 20%, and 18% in T-mixed, T-black, and T-native soils, respectively, compared to pit planting. T-mixed fruits had superior marketable quality-larger size, higher weight, optimal moisture, and better pulp-to-peel ratio. T-mixed trenches improved root zone conditions, supporting better resilience and avoiding drainage issues of black soils. Overall, dragon fruit planting modules using trenches filled with a 1:1 mixture (T-mixed) of native (murrum) and black soil achieved the highest B: C ratio (1.85) and the shortest payback period (4 years), and can thus be recommended for enhancing dragon fruit productivity on shallow soils in degraded regions.

Basaltic site

Trenching

Filled-in soil trenches

Established orchard

Impacts and Upscaling: The technology has potential to bring a substantial portion of 26.5 million hectares of shallow basaltic rocky land in the Deccan Plateau including states like Maharashtra, Madhya Pradesh, Chhattisgarh, and Karnataka under dragon fruit cultivation. Dragon fruit trees planted in transformed fill-soil trenches can yield 13–40% higher fruits while maintaining quality, saving 30% irrigation water, and reducing fertilizer use by 25%. This innovation transforms rocky lands for commercial agriculture, crop diversification, and agro-tourism, thereby boosting the incomes and livelihoods of farming communities in degraded regions. With slight modification, the innovation can also be applied to other orchard crops.

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